Efficiency Droop in III-Nitride LEDs: overview and carrier lifetime analysis

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***Abstract*—Gallium Nitride based light-emitting diodes (LEDs) are on the verge of enabling mainstream solid-state lighting. Their efficiency, however, is limited by a phenomenon known as droop which quenches internal quantum efficiency at high current density. We will review recent experimental results characterizing droop, and compare them to the various theories proposed these last years to explain this phenomenon.**

I. INTRODUCTION

GaN-based LEDs are undergoing active research due to their crucial technological impact. Of particular importance is the optimization of the internal quantum efficiency (IQE) of the LED. Unfortunately, GaN-based LEDs suffer from a phenomenon known as efficiency droop, which causes a (non-thermal) roll-over of the IQE at high current density. Droop is an important phenomenon both in terms of applications, as it limits the efficiency of high-power LEDs, and from a scientific standpoint, as the underlying physical phenomenon is currently not well understood.

The origin of droop has been a subject of controversy these last years. Identifying the correct process is of importance, as it dictates which strategies can be employed to quench or mitigate droop. Among the most often cited hypotheses are:

- **localization effects** related to alloy fluctuations in the InGaN active region [1]: at high injection, carriers delocalize from the fluctuations and become more sensitive to non-radiative losses.

- **leakage effects:** at high current density, energetic carriers either escape from the active region or are not captured in it, and yield a leakage current across the *pn* junction. The intense piezo fields characteristic of c-plane InGaN heterostructure are expected to induce leakage in this scenario [2].

- **Auger scattering:** droop appears to be a bulk-like radiative phenomenon, whose carrier density ($\sim n^3$) is similar to that of Auger recombinations [3,4].

The Auger hypothesis was initially proposed based on resonant photoluminescence (PL) experiments, where it was argued that carrier transport effects (especially leakage) should be absent. However, later work questioned that assumption as evidence of leakage was reported in photoluminescence [5]. Another point of importance is the relationship between material parameters and droop: the onset of droop appears at lower current density in longer-wavelength LEDs, which contain more In [6].

II. RESULTS

In this contribution, we will present recent experimental results which aim at testing the aforementioned scenarios for droop.

We will first show why droop appears to be a bulk-like phenomenon, rather than transport-related. We will present biased PL measurements which quantify the magnitude of the leakage current, and show that droop is not correlated to an increase in leakage. We will also employ PL measurements to illustrate how droop appears to scale with carrier density, the onset of droop being delayed in thick double-heterostructure active regions.

In a second part, we will present differential carrier lifetime measurements, which aim at characterizing the various recombination processes in InGaN heterostructures [7]. By coupling these measurements with calibrated measurements of IQE, we access the radiative and non-radiative carrier lifetimes, as well as the carrier density. We will review recently published results, which show that

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droop is caused by the onset of a high-order non-radiative process, and confirm that lifetime measurements are quantitatively compatible with the hypothesis of Auger scattering.

We will then present new carrier lifetime measurements on samples with various In contents, and discuss how the variations in droop can be understood by looking at the impact of piezoelectric fields on the carrier's lifetime.

III. References

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